Practical Spectral Capture Systems For Museum Imaging

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Abstract

Spectral imaging systems for capturing museum artwork have not moved beyond the research laboratory. System components and their selection criteria necessary to assemble a complete system are explored in this paper categorically. The final system is practical if it meets the criteria of speed cost and accuracy necessary to act as a direct replacement for the traditional RGB based digital imaging systems in museum photo studios. It is hoped that the advantages of spectral imaging will be widely recognized and adopted once a practical system is available.

Introduction

A spectral capture system is effectively an imaging spectroradiometer. Its purpose is to recover a spectra for every pixel in a captured scene. In museum imaging this means digitizing works of art. With knowledge of the spectral power distribution of the taking illuminant the reflectance of the artwork can also be estimated, although this is most effective for flat works.

Looking at why museums are currently capturing images of their collections we find their purposes can roughly be divided into three categories: documentation, academic research and commercial. Spectral based systems offer benefits in all three of these areas and the move away from traditional trichromatic (RGB) capture is supported by a broad range of benefits.

The filters selected by camera sensor manufacturers fundamentally limit the color accuracy of RGB systems. Due to these limitations museums often spend significant time visually editing their captured images to improve their color accuracy. Spectral systems offer increased accuracy and can completely remove the need for visual editing. This means that the images can be used for analytical applications such as monitoring long-term color changes or spatially mapping the distribution of pigments within artwork. The captured reflectance data can be used to render images with many different intentions. For example, prints can be made to match the original when viewed under the tungsten lighting often found in galleries independent of the studio capture illumination.

Currently, many spectral capture systems exist but they remain mainly in academic and research environments; none have been widely adopted by museums. For this to occur the system will need to meet the requirements of a production photo studio. The main components and tasks of a spectral capture system are shown in Figure 1. The goal of this paper is to explore the requirements and compromises needed to select the components needed for a practical museum imaging system.

For a system to be practical we mean that it can efficiently be used as a direct replacement for a traditional RGB camera in a photo studio. The camera system must be configured to easily handle the majority of subjects and shooting situations and be adaptable enough to accommodate the exceptions. With a limited budget it is advantageous to reuse as much equipment as possible from the museum's photo studio. This includes, lighting, rigging, cameras, lens, etc. Reuse also comes with the

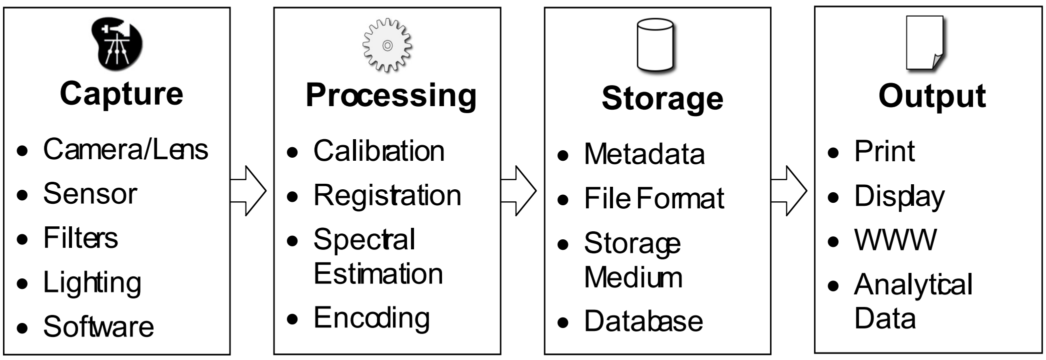

Figure 1: System components of spectral imaging system.

benefits of the photographer's familiarity and expertise. Adopting off-the-shelf hardware makes the system more practical as it is readily replaceable and comes with support from the manufacturer.

To understand why the spectral imaging systems in the research lab have been impractical for the photo studio we must first look at the major differences in these two environments. Some of the differences are shown in Table 1.

Cost, speed and accuracy are the main three, often conflicting, objectives that must be balanced to build a spectral capture system. If we return to the flow chart of Figure 1 and think about the list of available options for each system component we find our choices are extensive, often overwhelming. Some of the most common and promising choices for each section are examined below:

Table 1: Differences between research lab and museum photo studios.

Research Lab	Museum Photo Studio
• Small number of images captured • Maximum control over capture scene • Unlimited time • Interfaces that require expert knowledge	• High production volume (10k+/yr) • Unique requirements of priceless artwork (handling, light exposure, availability) • User friendly GUI necessary

Capture Components

Camera/Lens

The choice of camera type sets the form factor for the entire system. Large format view cameras offer full tilt/swing movements and the widest compatibility with sensors but are often difficult to align and focus precisely. Medium format cameras usually offer an optical view finder and a fast focal-plane shutter. Digital SLRs provide the sensor and camera in a single unit and also the least expensive choice. A system based around the large or medium format camera and lens system that the museum's photo studio already owns is likely the most attractive option. The highest quality lenses should be used to avoid chromatic aberrations that may become apparent over the wide spectral range of capture. Also, because the camera is being used as an absolute measurement device electronic control over the aperture and shutter may be needed to avoid introducing errors in multiple exposures or when returning to previous settings.

Sensors

The sensors of commercially available digital cameras generally have one of two geometries, Linear-arrays and Area-arrays. A Linear-array consists of series of sensors with high resolution in one dimension (12k) and often three are integrated to provide simultaneous RGB capture. The advantage to using this type of sensor is that very high resolution is possible by scanning the array across the other spatial dimension. The disadvantages to this type of sensor are that single pixel defects affect an entire row of the image and long integration times are impractical.

The second category of sensors, area-arrays solves the two additional problems of capturing moving subjects and utilizing pulsed lighting. The largest currently available area-arrays are 22M pixels and are already used in high-end RGB based systems. The resolution of these arrays may still not be high enough to capture the smallest details of a large painting in a single exposure. However since the goal is be competitive with traditional RGB systems this may be an acceptable compromise. The necessary resolution can be gained by shooting details of areas of interest or by stitching together a mosaic of multiple exposures.

At this time the best sensor technology for a spectral imaging system is likely CCD (Charge-Coupled-Device). Nothing about the spectral sensitivity of CMOS (Complementary Metal Oxide Semiconductor) sensors precludes their use, but typically the largest area-arrays are only available as CCDs.

Filters / Spectral Selection

From the standpoint of spectral accuracy, perhaps the most important part of a spectral camera is the set of spectral selection filters placed in front of the sensor. The filters can be used sequentially, arranged into a color-filter-array (CFA) or placed in front of multiple sensors. The most common types of filtration are described in Table 2.

Filter Type	Pros	Cons
Broadband Absorption filter	Inexpensive	Low peak throughput
Narrow Band Interference Filter	High Throughput	Angular dependency
Liquid-Crystal-Tunable-Filter (LCTF)	No moving parts	Temp. sensitive, high cost, angular dependency
RGB CFA + Broadband filters	Quick/Practical	Constrained by integrated RGB Filters

Table 2: Spectral Selection Filter type pro/cons.

In our own research we have evaluated these techniques and found the most practical solution to be to use a commercial RGB array-sensor (CFA array) with a series of broadband absorption filters.[1,2] In a single shot, the sensor collects sparse information through the CFA. Then, if the subject is stationary the sensor can be micropositioned to gain full color information at each. The capture sequence is repeated through a second absorption filter and the two three-channels images are assembled into a single six channel spectral image. This technique is an augmentation to what is already used in RGB micro-positioning backs by several manufacturers.

Lighting

Choosing lighting means specifying not only the type but the geometry for the imaging setup. For example diffuse lighting hides spatial structure but is more easier to setup repeatable, while direct lighting is used to emphasize surface structure and makes more pleasing images. In a recent project benchmarking museum digital imaging systems we found there are five main types of lighting are being used in the digital photo studios; HMI, Tungsten, Xenon Strobes, Fluorescent, and HID.[3,4]

What makes a lighting source suitable for spectral imaging is similar to the requirements for conventional digital photography. It must be bright, temporally stable, and the level of UV and IR reaching the artwork must be controlled to levels acceptable to the museums conservators. With a low number of capture bands the spectral power distribution (SPD) of the lighting can significantly affect the colorimetric accuracy of the system (mu-factor). This is especially true if the capture illuminate is different from the intended rendering illuminant. Allowing flexible lighting is one of the key requirements of a practical spectral capture system and one of the only areas where the photographer will retain creative control.

Capture Software

The capture software should be easy to use. Integrating the steps of meta-data collection and spectral calibration into a single software environment. Only the minimal controls (likely just aperture and exposure) should be presented to the photographer to avoid changing them accidentally. A tightly integrated solution will likely require the cooperation of the camera manufacturer.

Image Processing

Many image-processing libraries have already been written. Most can readily be adapted to process spectral images. Using open source software such as VIPS[5] for image processing and ITK[6] for image registration means that the cost to the museums is kept low and a base of expertise and community of helpful users already exists. However, the end user is most likely the photographer not the programmer and the complexity of these libraries needs to be hidden behind a simple interface. For example, in our own research we have chosen to implement all image processing packages as a series of Photoshop plug-ins. To facilitate batch processing and peer-review of our algorithms they will also be made available as source code that can be compiled into largely platform independent console applications.

Data Storage/Meta Data

Ideally all of the digital information captured by the camera will be saved in the form it is recorded. The main reason for this is errors and oversights in the workflow implementation that change the data can be systematically and retroactively corrected once they are discovered. It is inevitable that later somebody smarter will come along later with a better algorithm and saving the original data will all them to reprocess the images. There is no universal format to store cameras raw data without first performing some form of modification. Adobe's digital-negative-format (DNG[7]), for example requires defective pixels to be mapped out before the image is saved. TIFF[8] (Tagged

Image File Format) is probably the most practical format to adopt at this stage. However, the method of storing the spectral image data and meta-data within the TIFF file must be well documented so that in the future when the original software, operating system, or hardware isn't available the spectral images are still accessible. The specific meta-data that should be stored with the images is an area of active discussion and standards are being worked on that address digital image archives[9]. Finally, the large file sizes of the spectral images dictate that hard-disks are probably the most suitable physical storage method.

Image Output

A pure spectrally matched print is the holy grail of this field. While research in this direction continues, advances have been made to leverage spectral information to produce better colorimetric prints. Maintaining the spectral image archive means that as these advances are made output can take advantage of them. Until then, we must compromise to service the needs of the publishers, researchers, web developers who rely on the digital images produced by the museums. The most expeditious path is to render the spectral images colorimetrically and output them through the ICC workflows that exist in the industry.

Conclusion

The component parts of a spectral imaging system each represent a balance between time, cost and accuracy. Their advantages and disadvantages must be weighed to reach a practical system. The system will be compared to existing RGB based digital imaging approaches in ultimately determining whether museums adopt spectral imaging as a normal practice.

It is important to realize that spectral imaging is not a panacea and can not solve all imaging problems. For example, modern art contains a broad spectrum of materials with unique physical properties. Accurately capturing spectral images of complex gonio-chromatic metallic, iridescence and fluorescent pigments will continue to be a challenge. In these situations It may be most beneficial to seek solutions that focus on recording how a human observer would perceive the piece rather than try to model it's physical properties. We end with the assertion that a practical spectral imaging system is achievable and should be pursued.

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